Physical and Optical Structures in the Upper Ocean of the East (Japan) Sea

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LONG-TERM GOALS

This study fits within our broader scientific efforts to understand:

- Physical and biological responses of the upper ocean to atmospheric forcing and how these penetrate to the interior.
- The dynamics and biological influences of instabilities, secondary circulations and vertical motions associated with upper ocean fronts.
- Physical and bio-optical transitions between coastal and central basin waters.

OBJECTIVES

We seek to understand the processes that control physical and bio-optical variability in the upper ocean of the East/Japan Sea. Specifically, we are interested in:

- The upper ocean response to strong wintertime forcing (Siberian cold air outbreaks) at the subpolar front.
- The resulting formation, subduction, and spreading of intermediate waters.

- The dynamics of the subpolar front.
- Contrasting seasonal and coastal/central basin bio-optical variability.

APPROACH

Two cruises, the first in May 1999 followed by a second in January 2000, sampled upper ocean and atmospheric boundary layer (Drs. C. Dorman, SIO, R. Beardsley and J. Edson, WHOI) variability in the Japan/East Sea. The spring cruise focused on frontal dynamics, characterizing bio-optical variability associated with the spring phytoplankton bloom and documenting the location, range and properties of water masses formed at the subpolar front during the preceding winter. The wintertime cruise documented the upper ocean response to a series of cold air outbreaks with particular attention to processes associated with water mass formation and subduction at the subpolar front. Both cruises employed a towed, undulating profiler (SeaSoar) to make highly-resolved observations of the upper ocean. We used real-time remotely sensed sea surface temperature and ocean color images (R. Arnone and R. Gould, NRL) to determine the location of the subpolar front and to select intensive survey locations. Real-time access to remotely sensed imagery allowed us to modify our sampling in response to changes in the front. Repeated intensive grid surveys provided approximately synoptic, three-dimensional coverage while a sequence of longer sections documented oceanic and atmospheric boundary layer variability away from the front. In addition to the suite of physical and bio-optical sensors carried by SeaSoar, we employed a shipboard Acoustic Doppler Current Profiler (ADCP) and GPS navigation to measure upper ocean currents. Sampling included a limited number of hydrographic stations and optical profiles off the Korean coast and across the subpolar front. Professor S. Yang (Kwangju University) was responsible for additional biological and bio-optical sampling (e.g. nutrient analysis, pigments). Dr. M. Suk (KORDI) and colleagues provided additional support.

WORK COMPLETED

We have successfully completed both SeaSoar cruises, the first of which was documented in the 1999 annual report, and will not be discussed here. The second (wintertime) cruise took place between 16 January and 4 February, 2000 aboard the R/V Roger Revelle. The field program involved scientists from the United States, Korea and Russia and included specialists in physical oceanography, biological oceanography, bio-optics, boundary layer meteorology and remote sensing. Although extensive cloud cover interfered with remote sensing efforts, we obtained useful imagery frequently enough (5-7 day intervals) to guide our sampling strategy. Motivated by frontal structures observed in the remotely sensed imagery and a desire to maximize available sampling time, we chose to reoccupy the region surveyed during the previous spring (Fig. 1). SeaSoar sampling included a long section extending across the western half of the basin and four intensive, quasi-synoptic surveys of the subpolar front. Our measurement program combined surveys dedicated to resolving the three-dimensional structure of the subpolar front with several long north-south sections. These extended sections focused on capturing variability associated with a warm, fresh eddy situated north of the front and investigating atmospheric boundary layer structure across the frontal region. Shipboard sensors made continuous measurements of meteorological variability while atmospheric soundings were carried out each day to obtain vertical profiles of temperature, humidity, pressure and winds. Underway measurements of absorption, scattering, attenuation and remote sensing reflectance were also collected (Dr. R. Arnone NRL).

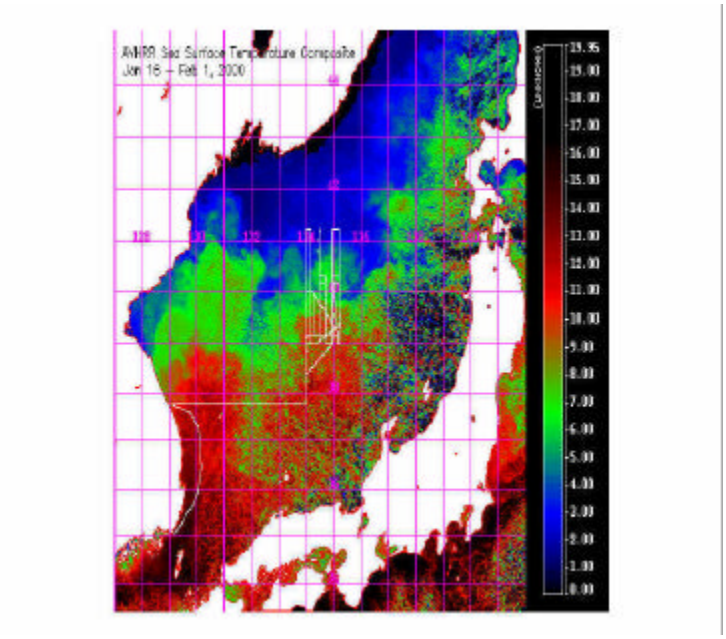

Figure 1. Composite AVHRR sea surface temperature image from 16 Jan - 1 Feb 2000 (R. Arnone, R. Gould and C. Chan). The white line marks the SeaSoar survey track.

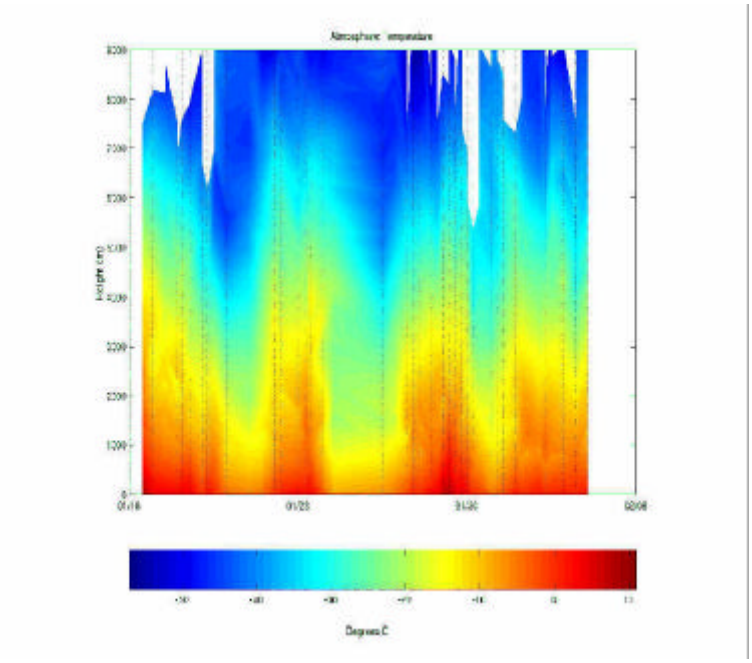

Figure 2. Time series of underway atmospheric temperature soundings (C. Dorman, SIO). The three severe temperature drops mark the passage of cold air outbreaks.

RESULTS

The wintertime cruise spanned three distinctive Siberian cold air outbreaks (Fig 2), which brought strong winds and cold, dry air to our sampling region near the subpolar front. Surface waters north of the

front were warmer than anticipated from previous observations, though the warmest waters just north of the front were associated with an eddy (Figs. 3 and 4). Following the passage of the first cold air outbreak, the front sharpened and surface temperatures cooled by nearly 2 °C (Fig. 3), presumably through some combination of net surface cooling, convective overturning and horizontal advection. An anticyclonic eddy occupied the region just north of the subpolar front, characterized by warm (6 °C), fresh (< 33.9) waters extending below 250 m and clockwise surface flows of nearly 0.5 m/s (Fig. 4). Mixed layer temperatures cool to 2 °C north of the eddy, with only weak stratification in the underlying pycnocline. South of the front, shallower (50 m), warmer (> 10 °C) mixed layers rest on top of a strongly stratified pycnocline (Fig. 4). Of particular interest are the weakly stratified, negative salinity anomaly watermasses found beneath the mixed layer base south of the front. These features have horizontal scales of O(10 km), vertical scales of O(10 m) and appear between the 26.5 kg/m^3 and 27.0 kg/m^3 isopycnals in nearly all of the cross-front sections. Selected sections also exhibit elevated bio-optical variability associated with negative salinity anomaly regions closest to the frontal interface. North of the front at the western end of the sampling grid, deep chlorophyll and optical signatures were observed to at least 150 m. Within the front, chlorophyll and enhanced inherent optical properties penetrated to about 100m. Maximum chlorophyll concentrations within the front were about 1 µg/l. The density range, weak stratification and observed salinities within these features are consistent with the characteristics expected of northern waters that have been subducted along the front and injected beneath the southern-side mixed layer. Along-front horizontal advection also probably plays a strong role.

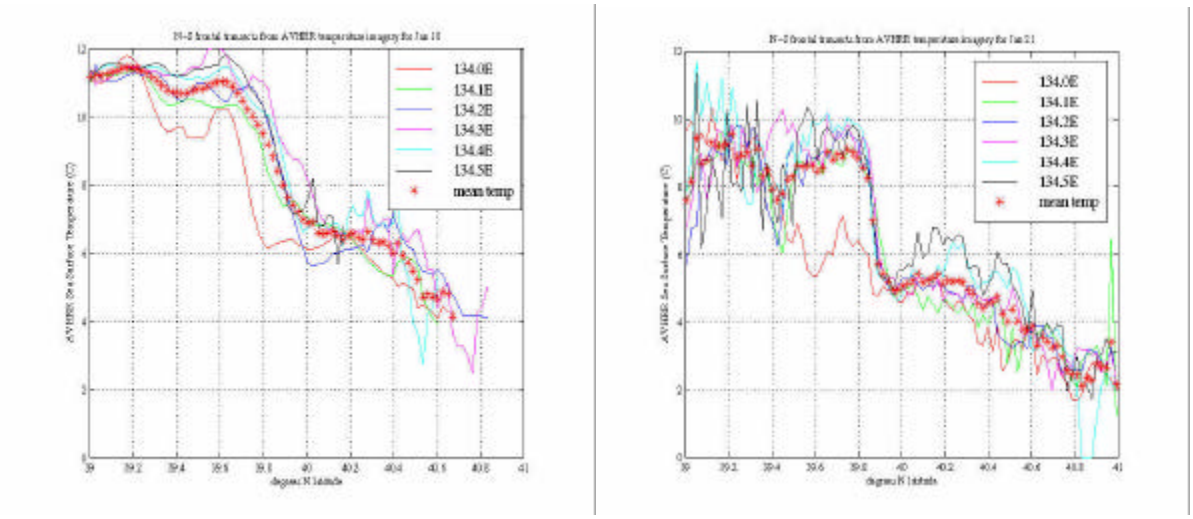

Figure 3. Remotely sensed sea surface temperature along several sections across the front (R. Arnone, R. Gould and C. Chan, NRL). The 18 Jan sections have been smoothed in the cross-front direction while the 21 Jan sections have not. A strong cold air outbreak occurred during the period between these two dates.

RELATED PROJECTS

Our efforts are part of an intensive, multi-investigator study of the Japan/East Sea. We intend to collaborate closely, both in the measurement and analysis phases, with other Japan/East Sea projects. In particular, we anticipate cooperation with the following components:

Satellite Characterization of Bio-Optical and Thermal Variability in the Japan/East Sea, B. Arnone, (NRL).

Atmospheric Forcing and its Spatial Variability over the Japan/East Sea, R. Beardsley, A. Rogerson (WHOI) and C. Dorman (SIO).

Optical Properties as Tracers of Water Mass Structure and Circulation, G. Mitchell, D. Stramski and P. Flatau (SIO).

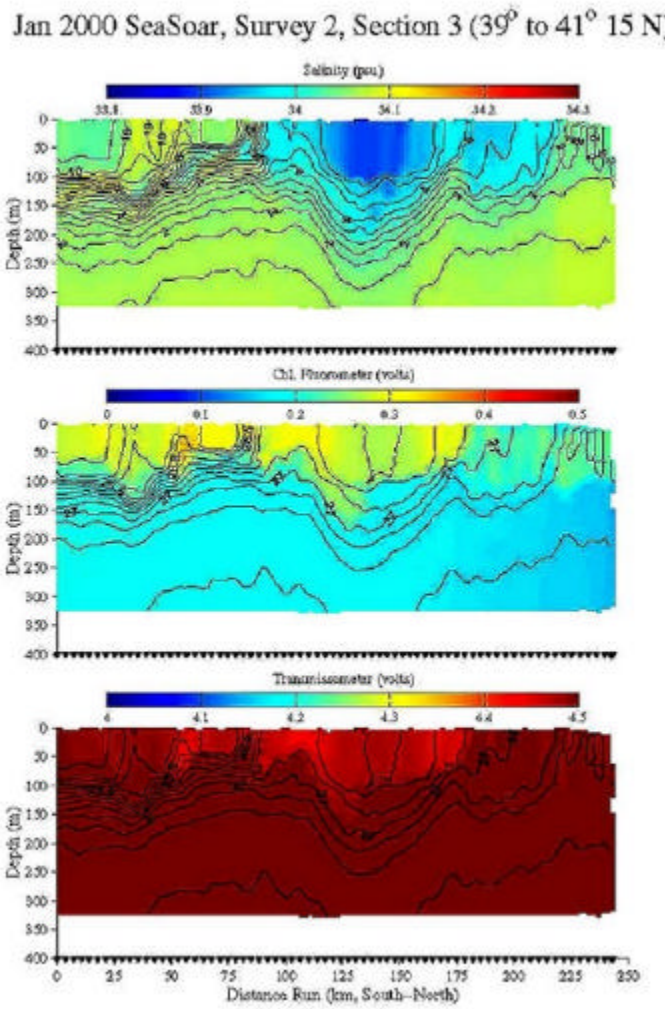

Figure 4. SeaSoar section (third section counting west to east across the survey pattern) across the subpolar front, occupied immediately following the first cold air outbreak. Temperature is contoured in the top panel, while potential density is contoured in the bottom two frames.

Modeling Support for CREAMS II: Oceanic and Atmospheric Mesoscale Circulation and Marine Ecosystem Simulations for the Japan/East Sea, C. Mooers and S. Chen (University of Miami).

Wind Forcing of Currents in the Japan/East Sea, P. Niiler (S.I.O.), D. Lee (Pusan National University) and S. Hahn (National Fisheries Research and Development Institute).

Observations of Upper Ocean Hydrography and Currents in the Japan/East Sea using PALACE Floats, S. Riser (University of Washington).

Hydrographic Measurements in Support of Japan/East Sea Circulation, L. Talley (SIO).

Shallow and Deep Current Variability in the Southwestern Japan/East Sea, R. Watts and M. Wimbush (University of Rhode Island).

IMPACT/APPLICATION

Highly resolved, three-dimensional upper ocean measurements provide a unique picture of the integrated effects of wintertime water mass formation in response to strong atmospheric forcing. Simultaneous measurements of bio-optical properties contrasts conditions on either side of the front and permit us to study the role of dynamics in controlling bio-optical variability. Both at the subpolar front and off the Korean coast, SeaSoar surveys provide bio-optical measurements of unprecedented synopticity and horizontal resolution.

TRANSITIONS

None.

PUBLICATIONS

Lee, C. M., C. E. Dorman, R. W. Gould and B. H. Jones (1999) Perliminary Cruise Report: Hahnaro 5-Dynamics, Biology, Optics and Meteorology of the Subpolar Front in the Japan/East Sea. Technical Memorandum, APL-UW TM 3-99, Applied Physics Laboratory, University of Washington, 65pp.

Fox, D.N., W.J. Teague, C.N. Barron, M.R. Carnes, and C.M. Lee, The Modular Ocean Data Assimilation System (MODAS), submitted to J. Atm. Ocean. Tech., 9/2000.